IPM Calibration Status and Plan for Run12

Roger Connolly

The RHIC IPMs frequently exhibit two non-physical ‘emittance’ measurement artifacts.

1. The beam emittance appears to decrease during the acceleration ramp
2. The reported horizontal and vertical emittances in a ring are different.

In Run 11 we measured the gain depletion of the MCPs in the IPMs by moving the beam across the IPM aperture. These measurements show the wear pattern and wear rates of the MCPs and allow us to generate gain corrections to place in the application.

As shown on the next slide, the gain depletion pattern of a MCP results in a measured profile that is wider than the true profile. This error depends on the beam size and gets larger with larger beams. For YV, without gain corrections, the measured emittance of a σ=4mm beam is 40% too large, but for a σ=2mm beam the error is less than 10%. Because of MCP depletion the measured beam size error decreases with smaller beam size which may account for the ‘emittance decrease’ on the ramp.

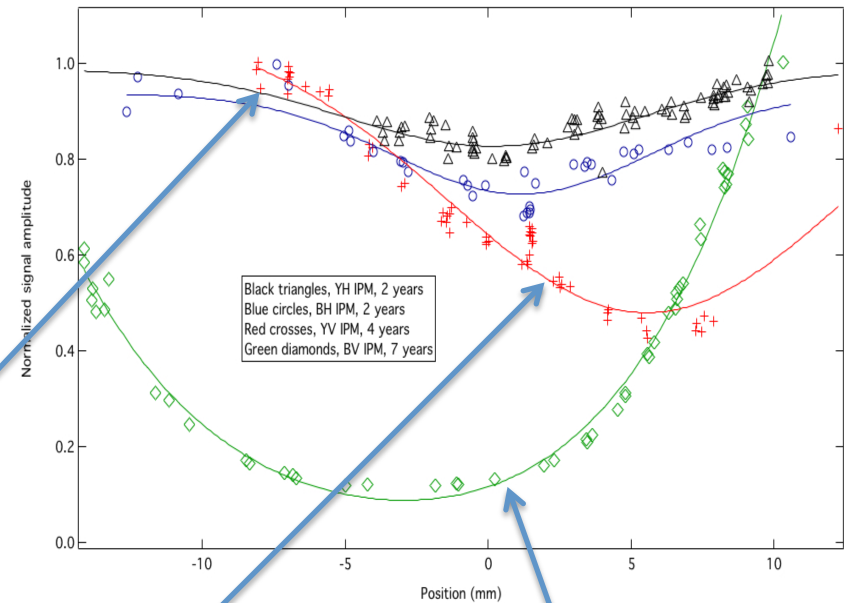
We plan on taking more calibration scans during Run12.

The ‘emittance disagreements’ among IPMs and the IPMs and other devices may be caused by inaccuracies in the optical model.

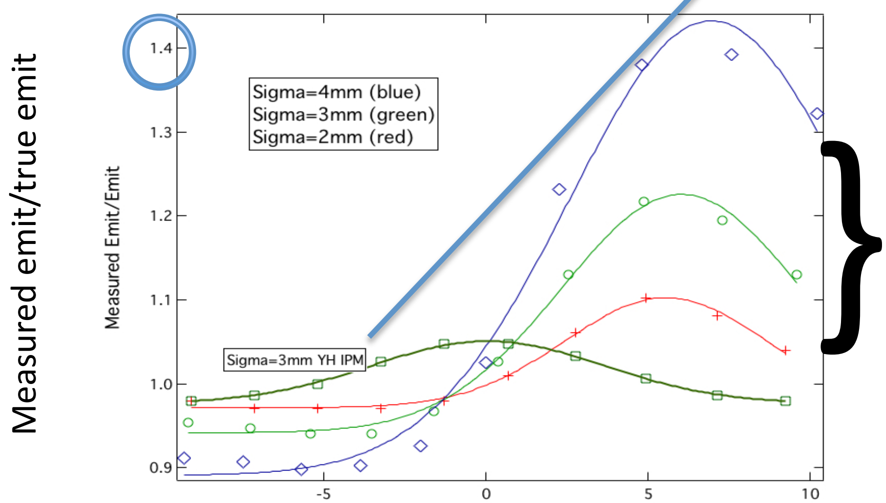
Following is a procedure for measuring the beam beta functions at the IPMs

Gain calibration scans

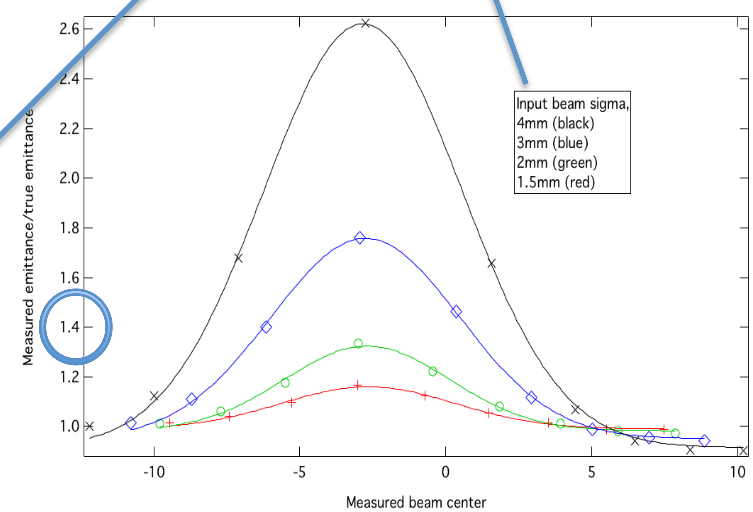
We move the beam over the measurement aperture of each IPM to measure the gain depletion of the MCP. These scans are done by placing a closed bump around each IPM. This plot shows normalized gain patterns for the four IPMs.



To study the effect of MCP aging on the IPM measurements I applied these gain patterns to simulated Gaussian beams of σ = 2, 3 and 4 mm and fit Gaussians to the results. The results are plotted for the Yellow IPMs on the left and the Blue vertical on the right.



Position of beam center



Simulation results for Blue vertical (7 yrs)

These simulations show that the measured width gets smaller as the beam size goes down. This may contribute to the observed decrease of emittance up the acceleration ramp.

Example of ‘emittance decrease’ on ramp

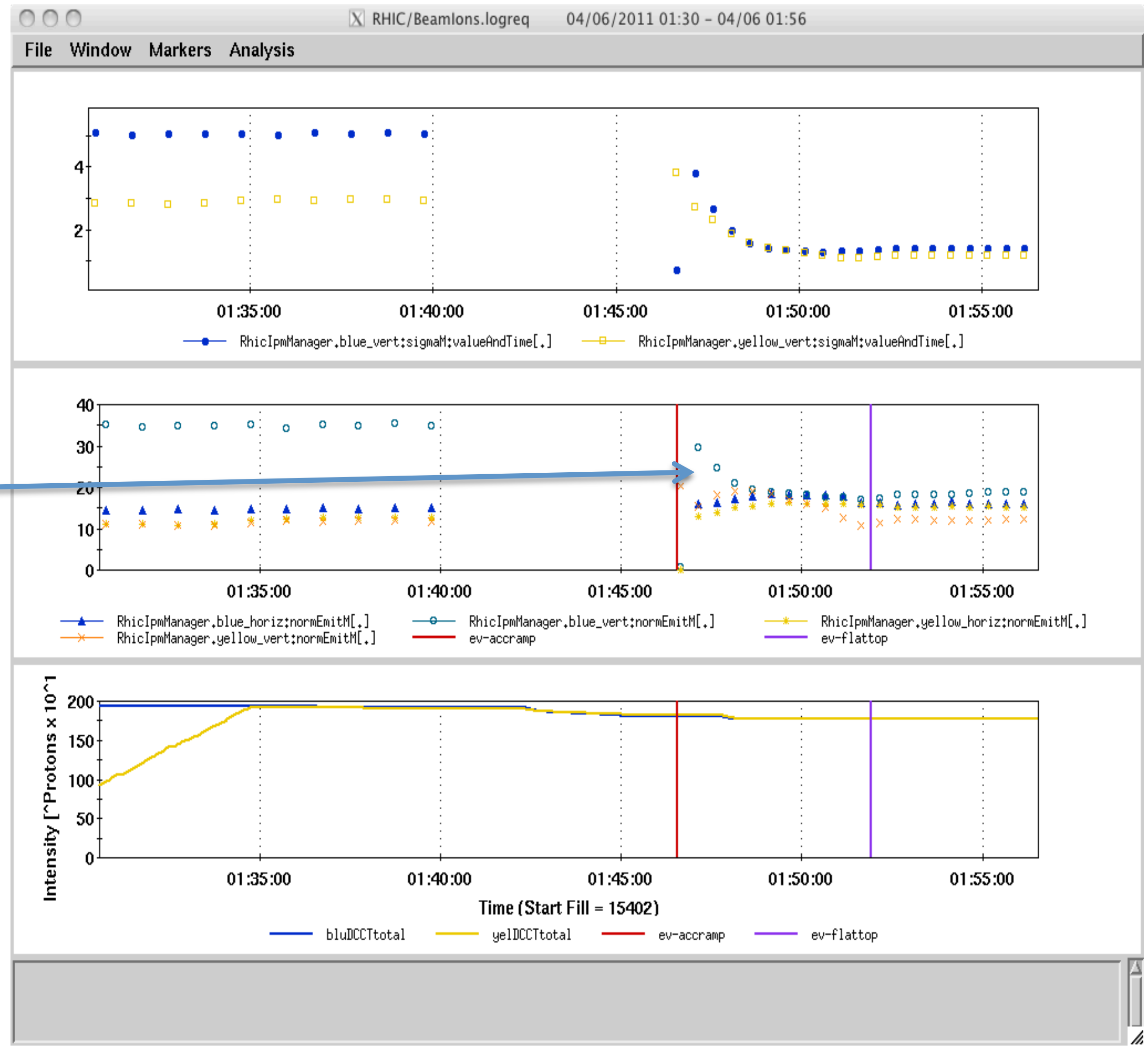
Here are the IPM measurements from fill #15402, before gain corrections were added to application.

The top plot are the BV and YV sigmas reported by the IPM. Both widths decrease during the ramp.

The middle plot shows IPM emittances. Both horizontal IPMs show nearly constant emittances up the ramp. The YV shows a slight decrease but the BV shows a decrease of about 50%.

From simulations a reported beam sigma of 5mm would be reported by an input beam of 3.7mm, an error of 1.35. This would result in an emittance error at injection of 1.8.

The indicated emittance at injection of 35π would correct to 19π, which is closer to the other three planes.



Inaccurate model beta function values may cause emittance disagreements among IPMs

There has been much discussion about the agreement of various emittance measurements made in RHIC. Within the IPM system there is concern that the reported values disagree between horizontal and vertical in the same ring, and the values disagree between rings.

Mei Bai made optics measurements at store during this proton run (rhic-pp_2011). The beta functions are measured at the BPMs. Each IPM is in a drift between two IPMs. The IPM application uses the model β to calculate emittance. The correct emittance can be found from the IPM emittances by:

$$\varepsilon_{true} = \varepsilon_{IPM}\left(\frac{\beta_{Model}}{\beta_{true}}\right)$$

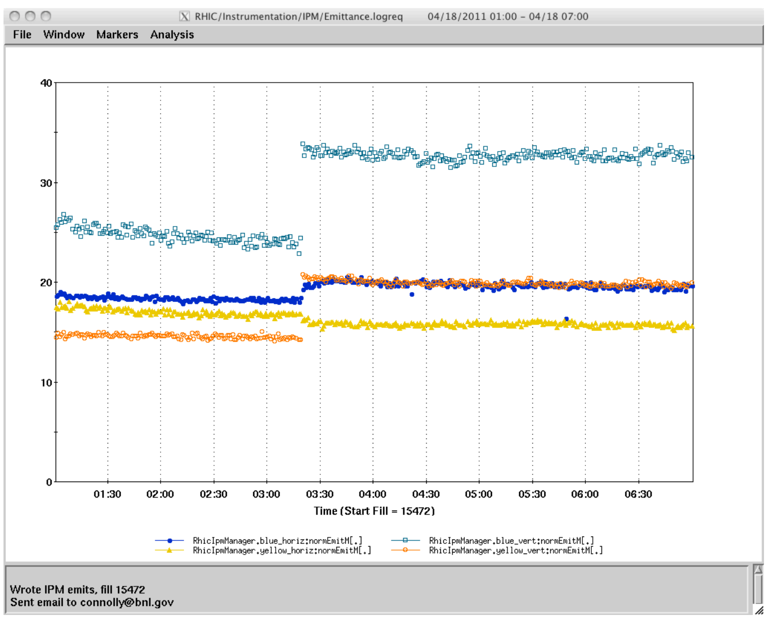
IPM measured beta functions, Mei Bai files 4/19/2011

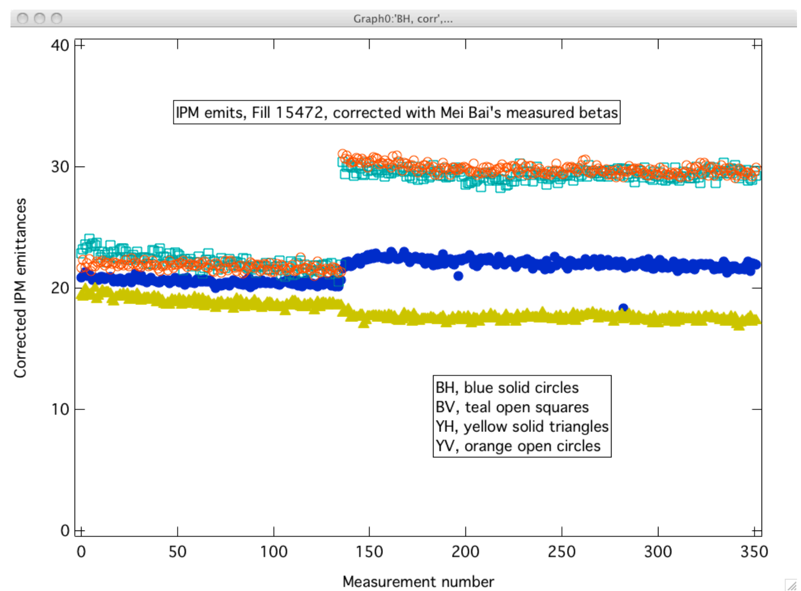
IPM	Meas beta	Model beta	Emit. corr.
BH	382m	427m	1.12
BV	200	178	0.90
YH	387	429	1.11
YV	121	184	1.51

The emittance correction is Etrue = Emeas (Beta, model/Beta, measured)

I applied these corrections to the IPM record from Fill 15472. The correction factors bring the four planes into closer agreement.

These values of β at the IPMs are approximate, but the ratios should be close to the actual ratios.





Measuring β function at IPM

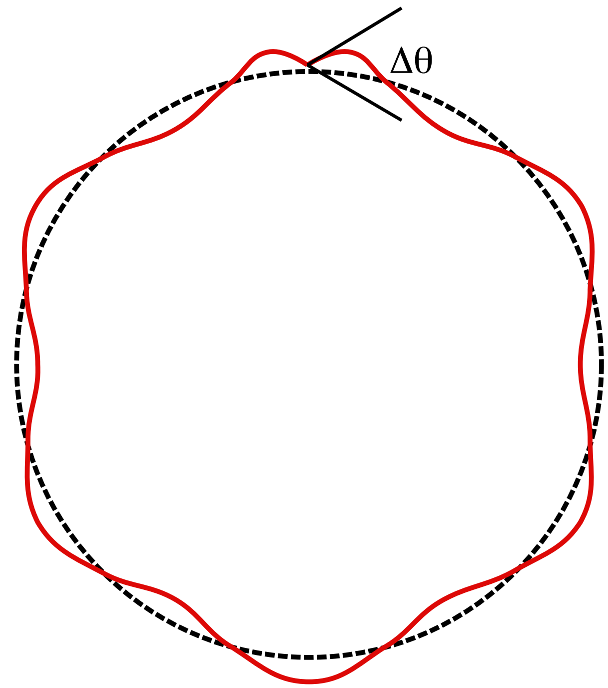
Placing an angular kick, Δθ, in the closed orbit at location Z=0 creates a new orbit whose distance from the original closed orbit, x(s), varies approximately sinusoidally with s. At location Z=s the orbit will be moved by x(s) where,

$$x(s) = \left(\frac{\Delta\theta\sqrt{\beta(0)}}{2\sin(\pi Q)}\right)\sqrt{\beta(s)}\left\{\cos\left[\pi\left(Q-\varphi(s)\right)\right]\right\}$$

Here β(0) is the beta function at the kick location, Q is the tune and ϕ(s) is the phase difference between Z=0 and Z=s.

If we know the kick angle and can measure the displacement at the kick location the beta function at the kick location is,

$$\beta(0) = \frac{2x(0)}{\Delta\theta}\tan(\pi Q)$$



Placing an angular kick in the closed orbit produces a new closed orbit which varies sinusoidally around the original orbit.

Consider measuring the beta function at the Blue Vertical IPM in Sector 2 warm section

There is a vertical corrector and BPM 0.5m apart near Q3 in all four warm sections. These two devices are separated by 0.0003π in phase advance. If the displacement at BPM b02-b3 is used to calculate β_m at the kick position x=(0) the true value of β(0) is:

$$\beta(0) = 1.0015\ \beta_m$$

Component	Name	S coord (m)	Beta (m)	μ
Q3 quad	bo2-qd3	2590.7		
Kick Vertical	bo2-tv3	2592.32	271.90	21.7109
BPM	bo2-b3	2592.80	267.24	21.7112
BV IPM	bo2-ipm3	2610.04	125.52	21.7262
BPM	bo2-b4	2629.07	34.32	21.773
Q4 quad	bo2-qf4	2631.11		

Values from ramp Au11v6, Q = 32.2182

The measurement will consist of several angular kicks by bo2-tv3 with measurements by BPMs bo2-b3 and bo2-b4 and by BV IPM. The displacement measured by bo2-b3 will be used to calculate the beta function at the location of the kick.

From the measured displacement at the IPM x(IPM) and the measured β(0) we find the beta function at the IPM, β(IPM) is,

$$\beta(IPM) = \frac{4x^2(IPM)\sin^2(\pi Q)}{(\Delta\theta)^2\beta(0)\cos^2\left[\pi\left(Q-\varphi(IPM)\right)\right]}$$

Numerical example

The orbit displacement at the location of the kick is,

$$x(0) = \frac{\Delta\theta}{2}\beta(0)\cot(\pi Q)$$

From the previous slide: β(0) = 271.90m and Q = 32.2182. A 20 μ rad kick produces x(0) = 3.32mm.

To estimate measurement error I use a BPM uncertainty of ±0.01 mm. The measured orbit displacement is therefore x(0) = 3.32 (1 ± 0.0032)mm. The error of the β(0) measurement is 0.32%:

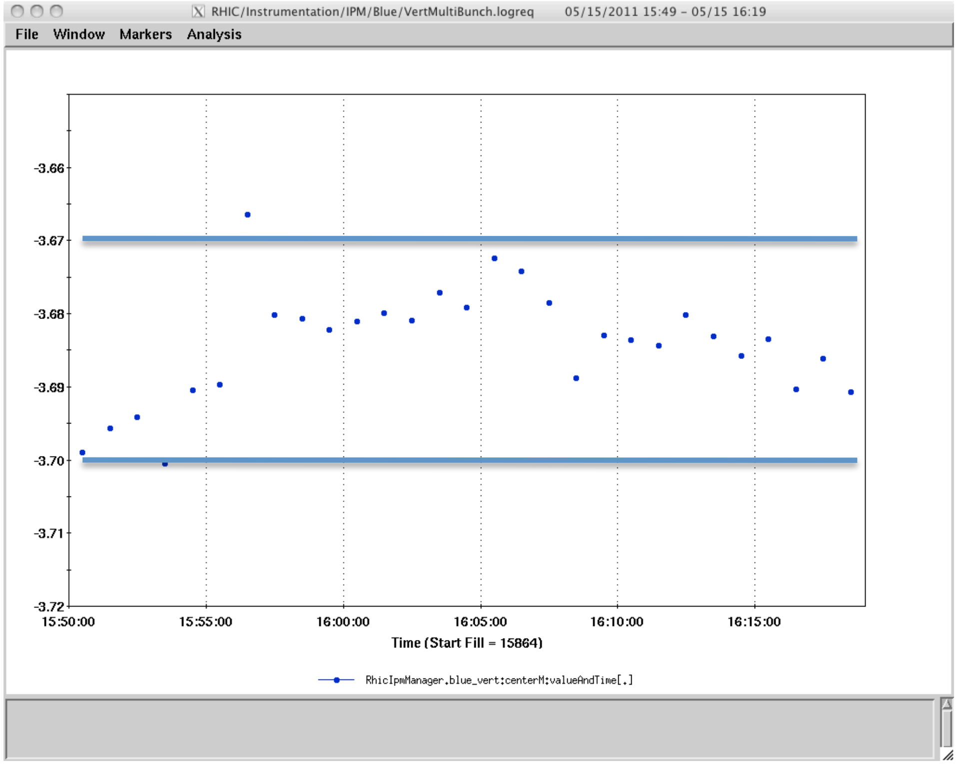
$$\beta(0) = 1.0015\ \beta_m\ (1 \pm 0.0032)$$

From the equation on the second slide this angular kick will produce a displacement at the IPM of x(IPM) = 2.06mm. The plot shows a 30 min record of the measured beam center position in BV during fill 15864 in May. The lines are 0.03mm apart. From this I estimate a beam-movement measurement error of ±0.015mm = ±0.73%.

$$\beta(ipm) \propto \frac{x(ipm)^2}{\beta(0)}$$

A rough estimate of measurement error is found by adding up the percentage error:

Beta function error < 2 (0.73%) + 0.32% ≈ 2%



Summary

In Run 11 we did calibrations on RHIC IPMs by moving the beam across their apertures and measuring the amplitudes of the responses.

Based on these experiments we know the MCPs are losing about 10% of their initial gain each year. We need to do these measurements each run.

MCP gain depletion is likely the cause of the indicated emittance decrease over the acceleration ramp.

The calculated vertical and horizontal emittances from IPM measurements usually do not agree.

During Run 12 we will measure the beta functions at the four IPMs. These measurement can be done by placing a 10-20μrad kick in the closed orbit by the –tv3 and –th3 kickers and measuring beam displacement in the –b3 and –b4 BPMS and the IPM.

Simulations indicate the measurement accuracy to be ±2%.